

Power ramp rate control and Individual Pitch Control of Variable Speed WT with DFIG

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Abstract—

Wind energy conversion systems have become a focal point in the research of renewable energy sources. This is in no small part due to the rapid advances in the size of wind generators as well as the development of power electronics and their applicability in wind energy extraction. The voltage of the direct driven permanent magnet wind generators (PMSG) is variable due to the intermittent nature of the wind energy. Fluctuating voltage and power is of major concern in the converter based grid connected wind generation systems. An inverter is essential for the interfacing of the wind source with the AC network. This paper discusses the interconnection issues of permanent magnet wind generators to local grid as per prevailing grid standards during healthy and fault conditions. The fault ride-through topology for PMSG has been demonstrated using MATLAB Simulink based simulation.

INTRODUCTION:

Wind energy is a reliable, natural and renewable electrical power supply. The high installed capacity of today's wind turbines and decreasing plant costs have shown that wind power can be competitive with conventional, more heavily polluting, fuels in the long term. Wind power growth with a 20% annual rate has experienced the fastest growth among all renewable energy sources since five years ago. It is predicted that by 2020 up to 12% of the world's electricity will have been supplied by wind power. Figure-1 shows the global cumulative installed capacity and global annual installed capacity. In terms of wind power generation technology, as a result of numerous technical benefits (higher energy yield, reducing power fluctuations and improving var supply) the modern MW-size wind turbines always use variable speed operation which is achieved by electrical converters. These converters are typically associated with individual generators and they contribute significantly to the costs of wind turbines. Between variable speed

wind turbine generators doubly fed induction generators (DFIGs) and permanent magnet synchronous generators (PMSGs) with primary converters are emerging as the preferred technologies. As a result of large-scale wind power generation, interconnecting large wind farms to power grids and the relevant influences on the host grids need to be carefully investigated. Wind farms are now required to comply with stringent connection requirements including reactive power support, transient recovery, system stability and voltage/frequency regulation. Further to increase the maximum power extraction the variable speed generators are employed. These variable speed generators necessitate a AC-DC-AC conversion systems. The generator side converter controls the electromagnetic torque, and therefore the extracted power, while the grid side converter controls both the DC link voltage and the power factor. Moreover, when designing the control strategy, it seems that the generator-side converter must control the extracted power as it is located closer to the incoming power. Hence, the

grid-side converter would control the DC voltage. Fulfilling the new grid codes constitutes one of the main challenges for the wind power industry. There are ride through requirements. Enhancing the operation of wind turbines in front of the grid faults is mandatory requirement. The wind turbines must stay connected to the grid during grid disturbances. They should continuously feed the reactive power in addition to limited active power. In modern wind turbines the increasing integration of power electronics enable to control the behavior of wind generation system under faulty scenarios. [1-5] In this paper, first, the grid connections requirements are listed as per IEEE standards. The system modeling for ride-through capability of the PMSG during fault condition is presented. Finally, the MATLAB Simulink based is used to validate the proposed ride-through topology.

MAJOR GRID PROBLEMS In Europe, substantial wind penetration exists today and will only increase over time. The impacts on the transmission network are viewed not as an obstacle to development, but rather as obstacles that must be overcome. High penetration of intermittent wind power (greater than 20 percent of generation meeting load) and may affect the network in the following ways and has to be studied in detail: A. Poor grid stability For economic exploitation of wind energy, a reliable grid is as important as availability of strong winds. The loss of generation for want of stable grid can be 10% to 20% and this deficiency may perhaps be the main reasons for low actual energy output of WEGs compared to the predicted output in known windy areas with adequate wind data. B. Low-frequency operation Low frequency operation affects the output of WEGs in two ways. Many WEGs do not get cut-in, when the frequency is less than 48 Hz (for standard

frequency of 50 Hz) through wind conditions are favorable, with consequent loss in output. This deficiency apart, the output of WEGs at low frequency operation is considerably reduced, due to reduced speed of the rotor. The loss in output could be about 5 to 10% on the account of low frequency operation. C. Impact of low power factor WEGs fitted with induction generators need reactive power for magnetizing. Normally in conventional energy systems, generators apart from supplying active power will be supplying a reactive power. But in case of WEGs fitted with induction generators, instead of supplying reactive power they absorb reactive power from the grid, which undoubtedly is a strain on the system. Suitable reactive power compensation may be required to reduce the reactive power burden on the grid. D. Power flow It is to be ensured that the interconnecting transmission or distribution lines will not be over-loaded. This type of analysis is needed to ensure that the introduction of additional generation will not overload the lines and other electrical equipment. Both active and reactive power requirements should be investigated. E. Short circuit It is required to determine the impact of additional generation sources to the short circuit current ratings of existing electrical equipment on the network. F. Power Quality Fluctuations in the wind power may have direct impact on the quality of power supply. As a result, large voltage fluctuations may result in voltage variations outside the regulation limits, as well as violations on flicker and other power quality standards.

III. WIND TURBINE TECHNOLOGIES FOR GRID REQUIREMENTS In this Section a brief review is presented of wind turbine technology aspects, associated with grid code compliance. Wind turbines are generally divided in two main technological categories: 1. Constant

speed wind turbines, which are equipped with squirrel cage induction generators directly connected to the grid. The rotational speed of the rotor is practically fixed, since they operate at a slip around 1%. Since the induction machine absorbs reactive power from the grid, connection of compensating capacitor banks at the wind turbine (or wind farm) terminals is necessary. Their aerodynamic control is based on stall, active stall or pitch control. A variation of this scheme utilizes a wound rotor induction generator and electronically controlled external resistors to the rotor terminals, permitting a very variation of speed (typically up to 10% above synchronous). 2. Variable speed wind turbines, the rotor speed of which varies significantly, according to the prevailing wind conditions. Two major types are available: The first utilizes a Doubly-Fed Induction Generator (DFIG) and a rotor converter cascade of reduced rating, while the second employs a synchronous or induction generator, the stator of which is interfaced to the grid via a full-power converter. In case of DFIGs the generator's stator is directly connected to the grid while the rotor is connected through a cascade of two voltage source converters (rectifier-inverter, connected back-to-back). Wind turbines with full converter use either a synchronous or an asynchronous generator, whose stator is connected to the grid via an AC/DC/AC converter cascade. In this case, the converter handles the total generator power to the grid and therefore no size economies are possible. The latest grid codes require that wind farms must remain in operation during severe grid disturbances, ensure fast restoration of active power to the pre-fault levels, as soon as the fault is cleared, and in certain cases produce reactive current in order to support grid voltage during disturbances. Depending on their type and technology, wind turbines can fulfill

these requirements to different degrees, as explained in the following. Starting with constant speed wind turbines, their low voltage behavior is dominated by the presence of the grid-connected induction generator. In the event of a voltage dip, the generator torque reduces considerably (roughly by the square of its terminal voltage) resulting in the acceleration of the rotor, which may result in rotor instability, unless the voltage is restored fast or the accelerating mechanical torque is rapidly reduced. Further, operation of the machine at increased slip values results in increased reactive power absorption, particularly after fault clearance and partial restoration of the system voltage. This effectively prevents fast voltage recovery and may affect other neighboring generators, whose terminal voltage remains depressed. Since the dynamic behavior of the induction generator itself cannot be improved, measures that can be taken in order to enhance the fault ride-through capabilities of constant speed wind turbines are the following: Ø Improvement in the response of the wind turbine aerodynamic control system, in order to perform fast limitation of the accelerating mechanical torque, to prevent rotor overspeed. Physical limitations of the blades and the pitch regulation mechanism impose a limit on the effectiveness of such an approach. Ø Supply of reactive power through static compensation devices at the wind turbine or wind farm terminals, such as SVCs or STATCOMs. These devices would provide high amounts of reactive power during faults, to effectively support the terminal voltage and therefore limit the magnitude of the voltage dip experienced by the wind turbines. Nevertheless, FACTS are complicated and costly devices, while there is an obvious limitation to the voltage correction they can achieve, particularly in the event of nearby system faults. Variable speed wind turbines, on

the other hand, present the distinct advantages of direct generator torque and reactive current control and the possibility to endure large rotor speed variations without stability implications. For this reason, grid disturbances affect much less their operation and, generally speaking, they are capable of meeting stringent requirements. In case of voltage disturbances, rotor over speed becomes an issue of much smaller significance, since a limited increase of speed is possible (e.g. 10-15% above rated), the rotor inertia acting as an energy buffer for the surplus accelerating power, until the pitch regulation becomes effective. In case of severe voltage dips, an energy surplus may occur in the electrical part, potentially leading to dc over voltages. This is dealt with via proper redesign of the converter controllers, increase of the local energy storage capacity (e.g. capacitor size) or even by providing local power dissipation means. However, even with variable speed wind turbines there still exist LVRT issues affecting their response. In the case of DFIG wind turbines, the direct connection of the generator stator to the grid inevitably results in severe transients in case of large grid disturbances. Hence, the stator contributes a high initial short circuit current, while large currents and voltages are also induced in the rotor windings, as a consequence of the fundamental flux linkage dynamics of the generator. Furthermore, the depressed terminal voltage reduces accordingly the power output of the grid side rotor converter, leading to an increase of the dc bus capacitor voltage. To protect the power converters from over voltages and over currents, DFIGs are always equipped with a device known as a crowbar, that short circuit the rotor terminals as soon as such situations are detected. Once the crowbar is activated, the DFIG behaves like a conventional induction machine, i.e. control is lost over the

generator. Notably, crowbar activation is possible not only at the instant of a voltage depression, but also in case of abrupt voltage recovery, after clearance of a fault. Conceptually, two crowbar options are available: · The passive crowbar, utilizing a diode rectifier or a pair of antiparallel thyristors to short the rotor terminals. The disadvantage of this option is the lack of control on the deactivation of the crowbar, leading to sustained operation with short-circuited rotor. · The active crowbar that uses IGBT switches to short the rotor. This enhances considerably the operation of the device, with a faster elimination of the rotor transients (typically within 100 ms) and therefore faster regain of control. After deactivation of the crowbar, full controllability over the wind turbine behavior is resumed. Hence, although voltage dips inevitably cause torque and power transients in the DFIG wind turbine, which excite the rotor crowbar protection for a limited time interval, the various implementations of the active crowbar can improve the stability of the wind turbine and its response to sudden voltage changes. Variable speed wind turbines with full power converters present the distinct advantage that the converter totally decouples the generator from the grid. Hence, grid disturbances have no direct effect on the generator, whose current and torque variations during voltage dips are much lower compared to the DFIG and the respective transients fade out faster, [6-8]. From the point of view of the reactive output power, the grid side converter has the ability to produce reactive current during the voltage dip, up to its rated current. Notably, this wind turbine type may exhibit better voltage control capabilities even than conventional synchronous generators. Another notable advantage of this type against the DFIG-based wind turbines is related with the behavior of the latter in case of unbalanced

disturbances. In such situations, the low negative sequence impedance of the induction generator may give rise to large rotor currents, whose frequency lies outside the controllers' bandwidth, resulting in the activation of the crowbar (or the disconnection of the stator) until the disturbance is cleared. Wind turbines can control their active power output by pitch control, while variable speed wind turbines have the additional capability for such control via variation of their rotor speed. Hence, power curtailment, ramp rate limitations and contribution to frequency regulation is possible, even for constant speed machines. In the latter case, however, the grid frequency is directly related to the generator slip and hence a change in frequency will transiently affect the active power produced by the wind turbine. In the case of variable speed machines, on the other hand, the generator power is directly controlled and therefore their primary frequency response is entirely adjustable via proper design of the control systems.

FAULT RIDE THROUGH REQUIREMENTS: The large increase in the installed wind capacity in transmission systems necessitates that wind generation remains in operation in the event of network disturbances. For this reason, grid codes issued during the last years invariably demand that wind farms (especially those connected to HV grids) must withstand voltage dips to a certain percentage of the nominal voltage (down to 0% in some cases) and for a specified duration. Such requirements are known as Fault Ride Through (FRT) or Low Voltage Ride Through (LVRT) and they are described by a voltage vs. time characteristic, denoting the minimum required immunity of the wind power station. The FRT requirements also include fast active and reactive power restoration to the pre-fault values, after the system voltage

returns to normal operation levels. Some codes impose increased reactive power generation by the wind turbines during the disturbance, in order to provide voltage support, a requirement that resembles the behavior of conventional synchronous generators in over-excited operation. The requirements depend on the specific characteristics of each power system and the protection employed and they deviate significantly from each other. The required fault behavior of a wind farm can be summarized into four requirements: For system faults that last up to 140 ms, the wind farm has to remain connected to the network. For supergrid voltage dips of duration greater than 140 ms, the wind farm has to remain connected to the system for any dip-duration on or above the heavy black line of fig. 2. During system faults and voltage sags, a wind farm has to supply maximum reactive current to the Grid System without exceeding the transient rating of the plant.

CONCLUSION:

For system faults that last up to 140 ms, upon the restoration of voltage to 90% of nominal, a wind farm has to supply active power to at least 90% of its pre-fault value within 0.5 sec. For voltage dips of duration greater than 140 ms, a wind farm has to supply active power to at least 90% of its pre-fault value within 1 sec of restoration of voltage to 90% of nominal. During voltage dips lasting more than 140 ms, the active power output of a wind farm has to be retained at least in proportion to the retained balanced super grid voltage.[8,9] It should be noted that in cases where less than 5% of the turbines are running, or under very high wind speed conditions where more than 50% of the turbines have been shut down, a wind farm is permitted to trip.

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